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Improved Health Monitoring Using Location Aware Sensor Routing Protocol

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***Abstract:** This project Improved Medical Health Monitoring Using LASER protocol (Location Aware Sensor Routing Protocol) is an innovative method to increase the efficiency of real-time health monitoring systems which make use of Wireless Sensor Networks. The high reliability and low latency requirements of this application is addressed by using Location Aware Sensing Routing Protocol (LASeR). The protocol uses location information to maintain a gradient field even in highly mobile environments, while reducing the routing overhead. This allows the protocol to utilize a blind forwarding technique to propagate packets towards the sink. Analytical expressions are derived and evaluated against the simulations. Extensive modeling and simulation of the proposed routing protocol has shown it to be highly adaptable and robust. The results highlight both the high performance of LASeR in various challenging environments and its superiority over the state-of-the-art.*

***Keywords:** LASeR, Mobile Wireless Sensor Networks, Health Monitoring, Routing, Performance Metrics.*

I. INTRODUCTION

Monitoring of health of patients in hospitals has vastly improved in the recent years due to advancements in technology. Recently, interest in wireless systems for medical applications has been rapidly increasing. With a number of advantages over wired alternatives, including ease of use, reduced risk of infection, reduced risk of failure, reduce patient discomfort, enhance mobility and low cost of care delivery, wireless applications bring forth exciting possibilities for new applications in medical market.

Portable devices such as heart rate monitors, pulse oximeters, spirometers and blood pressure monitors are essential instruments in intensive care. Traditionally, the sensors for these instruments are attached to the patient by wires; and the patient sequentially becomes bed-bound. In addition, whenever patient needs to be moved, all monitoring device has to be disconnected and then reconnected later. Nowadays, all of these time-consuming jobs could be terminated and patients could be liberated from instrumentation and bed by wireless technology. Integrated wireless technology, these wireless devices could communicate with a gateway that connects to the medical centre's network and transmits data to health data stores for monitoring, control, or evaluating in real time or offline after storage.

Continuous and pervasive medical monitoring is now available with the present of wireless healthcare systems and telemedicine services. In emergency situations, real-time health parameter is crucial.

II. MOBILE WIRELESS SENSOR NETWORKS (MWSNS)

A mobile wireless sensor network (MWSN) can simply be defined as a wireless sensor network (WSN) in which the sensor nodes are mobile. MWSNs are a smaller, emerging field of research in contrast to their well-established predecessor. MWSNs are much more versatile than static sensor networks as they can be deployed in any scenario and cope with rapid topology changes. However, many of their applications are similar, such as environment monitoring or surveillance. Commonly, the nodes consist of a radio transceiver and a microcontroller powered by a battery, as well as some kind of sensor for detecting light, heat, humidity, temperature, etc. There are several challenges in designing Mobile Wireless Sensor Networks (MWSN) such as mobility, link stability, scalability, production cost, hardware constraints, sensor network topology, power consumption.

III. Related Work

In general MWSN routing protocols take influence from two main research areas; WSNs and MANETs. WSNs are commonly considered to be static and so cannot handle the mobility of nodes, whereas MANETs are designed to cope with mobile nodes. Contrastingly to MANETs, most sensor networks only require data to flow in one direction; from source to sink. In addition to this the hardware and power constraints on these small sensor nodes means that protocols must have low computational complexity and low energy consumption. Energy is a major concern with battery powered mobility platforms since high energy consumption can dramatically reduce the lifetime of the network. MANET protocols are often defined as proactive or reactive.

A. Proactive And Reactive Protocols

The proactive protocols, such as optimised link state routing (OLSR), attempt to ensure that each node has an active path to every other node. This usually requires the flooding of topology data, which can cause huge amounts of congestion in large networks.

Contrastingly, reactive protocols, such as ad-hoc on-demand distance vector AODV), only discovers routes when they are needed. This can often reduce the overhead of control packets, making reactive protocols a more common choice for mobile networks. This can be seen by the number of reactive protocols that have been adapted from MANETs to MWSNs.

For example, AODV with pre-emptive self-repair is an adaptation of AODV designed for MWSNs, which, attempts to predict link breaks and find replacements. Another technique used is opportunistic routing, such as seen in geographically opportunistic routing, which splits up the network into sections. Using location information, each node then tries to forward the packet to a node in a section that is closer to the sink. It opportunistically attempts to transmit to the furthest section within its transmission radius, before trying increasingly closer sections.

B. Hierarchical Protocols

Alternatively, WSN routing protocols are categorised by their structure, as either flat or hierarchical. The hierarchical protocols, such as low-energy adaptive clustering hierarchy (LEACH), split the network up into clusters. Sensor nodes then forward data to a cluster head, which then forwards it to the sink. This approach has been shown to reduce energy consumption in static sensor networks. However, the requirement of nodes to first elect and then associate themselves with a cluster head can cause significant overhead, especially if nodes are frequently moving between different clusters.

Adaptations for MWSNs include LEACH-mobile and low-energy adaptive clustering hierarchy-mobile enhanced (LEACH-ME), which allow nodes to dynamically switch between clusters. This enables the protocol to adapt to changing topologies by providing a method of determining when a node is disconnected and should then join another cluster. In LEACH-ME, networks are made more stable by choosing the least mobile nodes to be cluster heads.

Mobility based clustering (MBC), works in a similar way to LEACH-M except that it utilises a more complex method of cluster head election, which takes into account estimated connection time, residual energy, the cluster heads node degree, and distance. These measures are used to generate a suitability metric, which allows nodes to make an informed choice about which cluster head to associate with. Another approach is presented which describes a protocol that is able to control the location of the mobile node in order to maximize the coverage of the sensors over the network area. In this way, it attempts to prolong the lifetime of the networks by maintaining low energy routes as an additional objective.

Zone based routing (ZBR) uses location awareness to define clusters. In this way, each node will know which cluster it is in by its current location. Cluster heads are determined by each node broadcasting a mobility factor, such that the least mobile node can be appointed.

C. Flat Protocols

Contrastingly, flat protocols, such as directed diffusion (DD), require no infrastructure, which makes them the preferred choice in mobile networks. Since they are not designed for mobile networks, data-centric braided multipath (DCBM) was adapted from DD to be used in MWSNs. DCBM lets the sink flood the network with a query, the path of which is recorded by the intermediate nodes. Once a node with the requested information receives the query it may respond along multiple paths towards the sink.

A state-of-the-art cross-layer protocol is proposed for MWSNs, mobility adaptive cross-layer routing (MACRO) is a recent routing solution that shares RSSI and speed information between layers. It saves energy by utilizing a MAC layer with an adaptive duty cycle. It also uses link quality information to ensure the route reliability. At this point it should also be noted that many delay tolerant networks are also considered to be MWSNs, however, the sparsity of the nodes require a different approach to the routing, and, as such, will not be considered here.

D. Gradient-Based Routing (GBR)

The literature suggests that the most suitable protocols for mobile networks are those with the least overhead, which makes gradient routing a particularly applicable technique. The static WSN protocol, gradient based routing (GBR), floods the network to set up a hop-count gradient metric at each node. Then nodes share their gradients with their neighbors, so that when a node wishes to transmit, it can select the neighbor closest to the sink as the next hop. Unfortunately, in an MWSN the changing topology would require the network to be flooded periodically in order to maintain the gradient, which would cause significant network congestion.

E. Proactive Highly Ambulatory Sensor Routing (PHASeR)

One recent gradient routing protocol is proactive highly ambulatory sensor routing (PHASeR), which targets MWSNs. The protocol also maintains a hop count through the sharing of local topology information, which can sometimes mean that the gradient is out-of-date. In addition, PHASeR utilises packet encapsulation, which allows it to transmit the data from more than one source in a single packet. However, this creates large packets and can cause long delays.

F. Greedy Perimeter Stateless Routing (GPSR)

Of primary relevance to the presented work is the location aware protocol greedy perimeter stateless routing (GPSR), which works in a similar way to GBR. The main difference is that the gradient is derived from location information in order to avoid flooding, as is also the case with LASeR.

IV. PROPOSED SYSTEM

A. Blind Forwarding Technique

In blind forwarding, a transmitting node broadcasts its packet to all of its neighbours; the neighbours then use the received gradient to determine whether they should forward the packet. This technique can be seen as far back as 1991 and has been used on multiple occasions for static WSNs. The main issue with using blind forwarding in mobile networks is maintaining an up-to-date gradient. Since, in LASeR, this is done using location information, the need to flood the network is negated making it an ideal solution for MWSNs.

The use of location awareness also produces the issue of the dead-end problem, in which a node is locally maximal and as such has no neighbours that are closer to the sink, which prevents the progress of any data received by this node. This is addressed in GPSR with the use of the right-hand rule. The partial-partition avoiding geographic routing algorithm was proposed as an alternative solution to the dead-end problem in GPSR. In comparison, LASeRs use of blind forwarding causes a single packet to take multiple paths through the network, which mostly alleviates the dead-end problem.

As such the contribution of this work is in a novel routing protocol designed for MWSNs, which utilises available location information to route packets towards the sink. The protocol also takes advantage of the blind forwarding technique to create a unique protocol, which requires very little control overhead, making it suitable for highly dynamic networks.

B. Protocol Description

The application of terrain mapping requires nodes to autonomously gather topographical information and report this to the sink. The data will need to be accompanied by some form of location information so that it can be mapped. This means that the nodes will be equipped with some method of localisation. This may be in the form of GPS, although the addition of GPS for every node requires significant cost and power. However, the dead reckoning localisation for mobile sensor networks technique proposed which provides a localisation solution. Hence it does not require all nodes to be equipped with a GPS module, yet still allows the nodes to move freely.

LASeR takes advantage of the available location information in order to route packets. In addition, it is likely that the nodes will be deployed to map an area for a certain time period. This means that as long as each node has enough power to last for the duration of the mission, the number of nodes will remain fixed. The traffic rate will also be relatively periodic as nodes will generate data based on a given resolution. The packet structure used is shown in Fig.1, in which n is the total number of sensor nodes, L is the length of one side of the square network area and Q_L is the quantisation level in meters. L_{data} is the number of data bits required by the application and the total packet length is given as L_p.

Field Name	Node ID	Location	Data	Priority Bit	Packet ID
Size (bits)	$\lceil \log_2 n \rceil$	$\lceil \log_2 (\frac{\sqrt{2} \cdot L}{QL}) \rceil$	L_{data}	1	$\lceil \log_2 n \rceil$
Total size (bits)	$L_p = 2 \cdot \lceil \log_2 n \rceil + \lceil \log_2 (\frac{\sqrt{2} \cdot L}{QL}) \rceil + L_{data} + 1$				

Fig.1 LASeR packet structure showing the five fields and their respective sizes.

The expression for the total packet size, L_P, is also given, where $\lceil \cdot \rceil$ indicates the ceiling function.affiliation lines.

C. Gradient Metric

The location information can be from any available geographic positioning technique, which may be application specific. Though it should be noted that some of these techniques require significant energy cost and their accuracy can be unreliable.

For the purposes of this paper, the location information is assumed to be perfect. This is to isolate the routing protocol such that its performance may be analysed without the added effects of an imperfect localisation technique. Each node's distance from the sink is quantised, such that an integer value can be used as a gradient. Conceptually, this creates radial bands emanating from the sink. A node's location corresponds to the location index of the radial band that it is in.

For example, if the quantisation level, Q_L, is 5 m and anodes Euclidean distance from the sink is 12 m, this would put it in the third radial band. Accordingly, the node would be assigned a location index of 3. These location indexes are the metrics used to create the gradient field. In terms of the field size, using a 40 m by 40 m network as an example, the furthest possible distance a node may be from the sink is 56.57 m. By splitting this length up into increments of 5 m, 12 segments are created. In order to store these 12 location index values, 4 bits are needed in the packet, which is corroborated by the location field size equation in Fig. 1.

D. Forwarding Data

The application LASeR uses blind forwarding to transmit packets, which means that the decision to forward a packet is made by the receiving node, rather than the transmitting node. Hence, when a node receives a packet it stores it in a queue until its next opportunity to transmit. Then the node will decide if any of the packets in the queue should be forwarded. If so, it will blindly transmit the packet to all of its one-hop neighbours, otherwise, it will drop the packet.

The decision to forward a message is made based on the received packets gradient metric. In this way, there are three possible actions to take based on a received packets' location information:

- If the location information indicates that the packet has come from a node that is further away from the sink, then it should be forwarded.
- If the packet has come from a node that is the same distance away from the sink, then it should be forwarded, with the priority bit clear, which will be discussed in the next section.
- If the packet has come from a node that is closer to the sink, then it should be dropped.

Overall, the location information is used as a gradient metric, which originates at the sink, as such, packets should be forwarded down the gradient. When the packets are forwarded they are updated with the current location index of the transmitting node. In this way, the receiving node will know from which direction the packet is coming and act accordingly. Since the choice to forward a packet is made by the receiving node, it is likely that multiple neighbours will decide to pass on the message, which subsequently creates route diversity. This route diversity will aid the protocols ability to deliver packets in a changing environment regardless of whether the topology is changing from the movement of nodes or the degradation of links in a fading channel. This will increase the redundancy of packets, which improves the reliability of the protocol as packets are more likely to be successfully delivered.

However, this added overhead will also mean that congestion may become an issue with high traffic levels. Subsequently, nodes are only allowed to transmit a packet once, which limits the amount of redundancy introduced into the network and enables LASeR to handle higher traffic levels. In addition, it should be noted that because LASeR does not use a routing table or path discovery techniques, if a node fails the protocol will simply continue to run and naturally adapt to the new state of the network, making LASeR very robust.

E. Packet Priority

Packets with the priority bit set are designated as priority packets, whereas packets with the priority bit cleared are designated as diversity packets. A diversity packet is one that has been forwarded by a node with the same location index as the one that transmitted it.

For example, a node with a location index of 3 broadcasts a priority packet to its neighbours. The neighbours with a location index of 2, store the packet for forwarding and the neighbours with a location index of 4 simply drop the packet. The neighbours that also have a location index of 3 clear the priority bit and store the packet for forwarding. The use of the priority bit increases the route diversity of the protocol and also helps to alleviate the dead-end problem.

F. General Operation

The operation of each sensor node during transmission can be summarised by the flow chart in Fig. 2, which shows how the protocol initially determines whether it should be transmitting or listening to the medium. This is based on information passed up from the MAC layer. It then either queue any data it hears from other nodes or selects a packet to forward. Packet selection is done on a first come first serve (FCFS) basis, where priority packets are always given precedence over diversity packets. In other words, the oldest packet with the highest priority is always transmitted first.

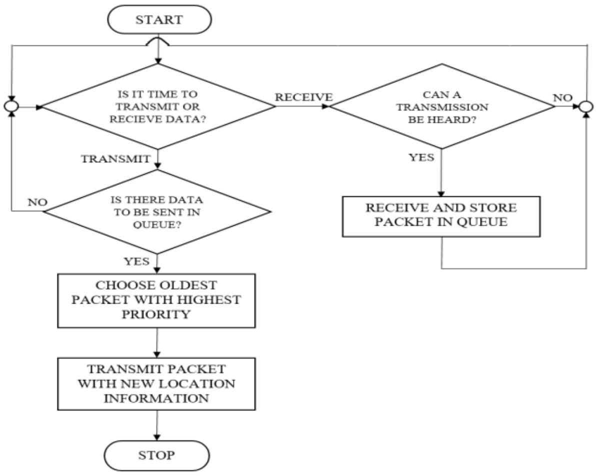

Fig.2 Flowchart representation of Transmitting sensor operation

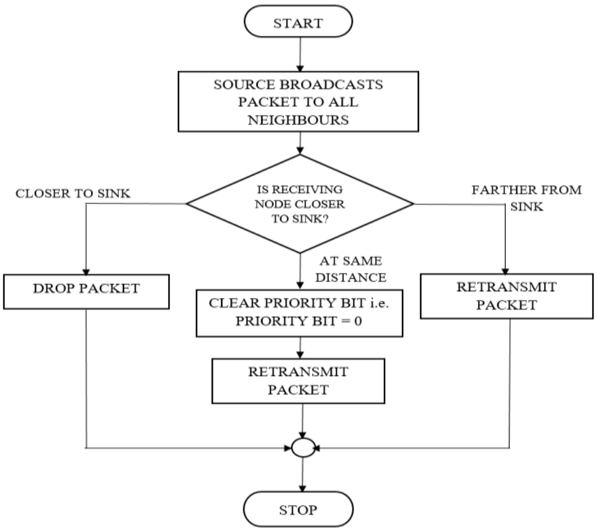

Fig.3 Flowchart representation of Receiving sensor operation

G. MAC Layer

The choice of MAC layer is an important aspect of this protocol; since LASeR uses blind forwarding it is likely that multiple neighbours will hear a node's broadcast and decide to forward the packet. This can cause significant MAC layer problems, especially when considering the hidden node problem. One of the most popular MAC layers is the 802.11 DCF MAC, which uses the technique of carrier sense multiple access (CSMA) with collision avoidance (CA).

This technique requires a node to first listen to the channel; if it is clear then the packet can be sent, else it should wait for a random amount of time before trying again. Using CSMA/CA in LASeR, a node may transmit to all of its neighbours, then each of them will listen to the medium. At this point it is likely that more than one of the neighbours will sense the channel to be free and try to transmit, causing collisions.

In addition, the 802.11 DCF MAC also defines the use of acknowledgements (ACKs) and a request to send, clear to send handshake. In LASeR, since multiple nodes receive the data, more than one node may respond with an ACK. These ACKs are likely to collide and potentially cause the unnecessary retransmission of a packet. A similar problem occurs with the handshake. This suggests that LASeR would be better served with a collision free MAC layer rather than a contention based one.

Since the target application is likely to use a fixed number of nodes for each mission, this work utilises a global time division multiple access (TDMA) scheme. This MAC allocates each node a time slot, which is sized to allow for the transmission of a single packet. The time slots loop cyclically, allowing each node to take it in turns to transmit contention free. The MAC can be adjusted for the specific number of nodes in the mission before deployment. Though it is not the scope of this work, long deployments will require some kind of synchronisation, for which there are a number of techniques surveyed in.

In addition, describes a working implementation of a TDMA based sensor network, which uses an out of band AM transmitter to maintain global synchronisation. Alternatively, if the location information is acquired via a satellite based system, each node may also synchronise its clock to the received time from the satellites.

V. Collection Of Recorded Data

Records of medical data from actual patients was collected from hospitals. Different parameters which need to be transmitted from the patients such as blood pressure, body temperature etc. were collected from different patients to be sent as sensor data. These values collected from the sensors were used as input to the simulation of the protocol. The medical data of different patients were collected from hospitals - Sri Sugam Hospital, #196, I. T. Highway (Near Diamond Engineering Company), Ponniamman Koil Bus Stop, Sholinganallur, Chennai-119 under the guidance of Dr. R. Srinivas M.B.B.S and under the guidance of Dr. K. I. Abdul Akbar Khan, B.Sc., M.B.B.S., F.A.C.P. (R.No.84848), Immanuvel Clinic, Kanathur, East Coast Road, Chennai-603 112.

TABLE I
Recorded Data – Set1

S.No	Age/Sex	Blood pressure (120/80 mm of Hg)	Body Temperature (98.6 F)	SpO_2 (100%)	Pulse (72-80)mm
1.	31/M	130/90	98.6 F	98%	84/mm
2.	24/M	110/80	100 F	98%	90/mm
3.	19/F	110/70	101 F	98%	96/mm
4.	30/M	110/70	98.6 F	98%	78/mm
5.	35/F	140/100	98.6 F	99%	76/mm
6.	23/F	120/70	98.8 F	98%	72/mm
7.	35/F	110/80	98.6 F	99%	74/mm

TABLE III
Recorded Data – Set 2

S.No	Age/Sex	Sugar FBS : 60-110 PPBS: 80-160	Cholesterol (<200)	Bilirubin Total :0.3-1.2 mg/dl Direct : 0-0.3 mg/dl
1.	42/M	FBS : 168 PPBS : 260	179	Total : 1.10 Direct : 0.4
2.	62/F	FBS : 160 PPBS : 176	192	Total : 0.7 Direct : 0.2
3.	50/F	FBS : 60 PPBS : 105	207	Total : 0.3 Direct : 0.4
4.	25/M	FBS : 91 PPBS : 110	172	Total : 2.3 Direct : 1.2
5.	53/M	FBS : 197 PPBS : 218	140	Total : 0.5 Direct : 0.2
6.	24/M	FBS : 60 PPBS : 136	140	Total : 5.7 Direct : 2.5

VI. System Implementation

In order to implement a mobile wireless sensor network, different modules implementing the sensors, mobile relay and sink (medical database or server) are written in Java programming language.

A. Performance Metrics

The different performance metrics can be calculated for the LASeR protocol by writing the required Java codes in the Netbeans IDE.

1) Average end-to-end Delay:

Average time between a node creating a packet and it being received at the sink. [1]

$$\mathbf{d_{end\text{-}end} = N[d_{trans} + d_{prop} + d_{proc} + d_{queue}] = Start\ time - End\ time}$$

where,

N	=	number of hops
$d_{end\text{-}end}$	=	end-to-end delay
d_{trans}	=	transmission delay
d_{prop}	=	propagation delay
d_{proc}	=	processing delay
d_{queue}	=	queuing delay

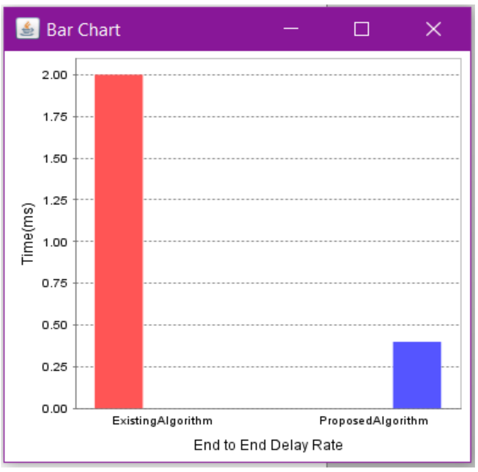

Fig.4. Average end-to-end Delay

2) Energy consumption:

The energy model represents the energy level of nodes in the network. The energy model defined in a node has an initial value that is the level of energy the node has at the beginning of the simulation. [1]

Difference between each data transmission expense of energy and initial stage,

EC = Initial energy – Current energy

It is measured per node and is measured in joules.

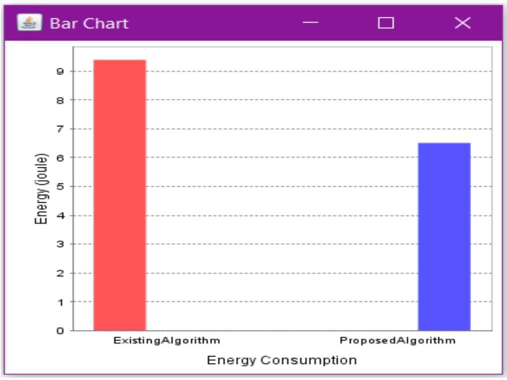

Fig.5 Energy consumption

3) Packet Delivery Ratio:

PDR is the ratio of the number of delivered data packet to the destination. This illustrates the level of delivered data to the destination. [1]

PDR = Σ Number of packet received / Σ Number of packet sent

where,

P_{tx} = Number of packets transmitted

P_{rx} = Number of packets received

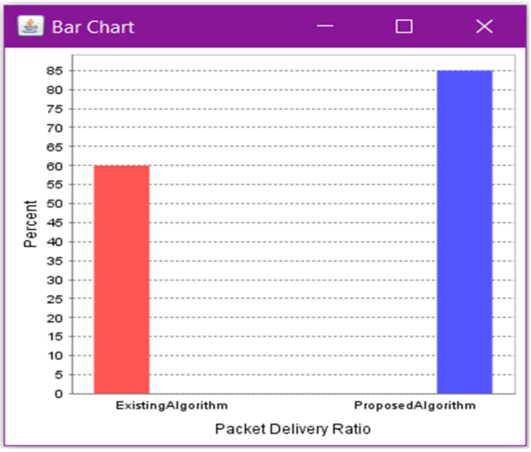

Fig.6.Packet Delivery Ratio

4) Packet Loss Ratio

Packet loss occurs when one or more packets of data travelling across a computer network fail to reach their destination. Packet loss is typically caused by network congestion. Packet loss is measured as a percentage of packets lost with respect to packets sent. [1]

Packet Loss = Number of packets sent – Number of packets received

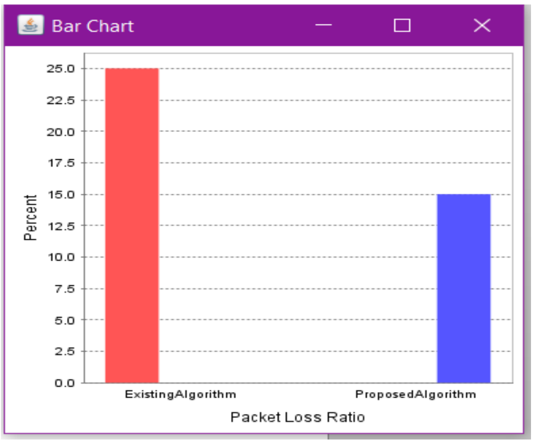

Fig7.\. Packet Loss Ratio

5) Throughput

Throughput is the amount of work that a node can do in a given time period. Throughput has been a measure of the comparative effectiveness of dense network that runs many tasks concurrently. [1]

$$\textbf{Throughput} = \frac{\textbf{Number of packets} \times 8}{\textbf{Data duration}}$$

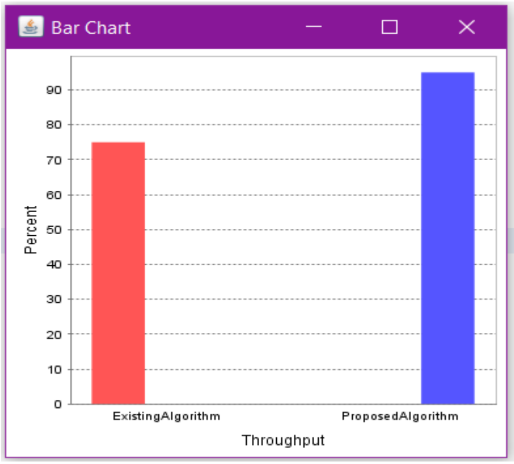

Fig8. Throughput

CONCLUSIONS

Thus the project has been developed to increase the efficiency of real-time health monitoring systems which make use of Wireless Sensor Networks. The high reliability and low latency requirements of this application are addressed by using Location Aware Sensing Routing Protocol (LASeR), a geographic routing protocol, designed for use in MWSNs. The protocol uses location information to maintain a gradient field even in highly mobile environments. Analysis of the modeling and simulation of the proposed routing protocol has shown it to be highly adaptable and robust. It has high PDR and low average end-to-end delay, making it reliable and fast. The overhead has also shown to be low, which gives LASeR a low level of energy consumption.

In future applications, the protocol used can be further optimized in the following aspects:

- Optimization in location determination and storage – using a different gradient parameter in order to reduce the packet overhead
  - Using GPS
  - Using Dead reckoning localization technique
  - Using Sectorized antenna
- Creating a balance between redundancy and energy consumption using priority bits.
- Better strategies for a node decide to drop the packet based on the priority bit value.

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